Effects of the representation of the crustal structure on seismic wave propagation modeling on the continental scale

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AIM OF THE WORK

Knowledge and representation of Earth's crustal structure is a crucial point when modeling seismic wave propagation at the continental scale (Molinari I. & A. Morelli, 2009). Here we review a new a priori crustal model, EPcrust-2009, that integrates various source of informations of the European crustal structure.

We focus our attention on the representation of crustal structure in 2D and 3D numerical models that often poses particular problems that are difficult to overcome, such as for example, how to honor the thin shallow layer (sediment) or represent the strong discontinuities in crustal structure through element interfaces of a geometry respecting mesh.

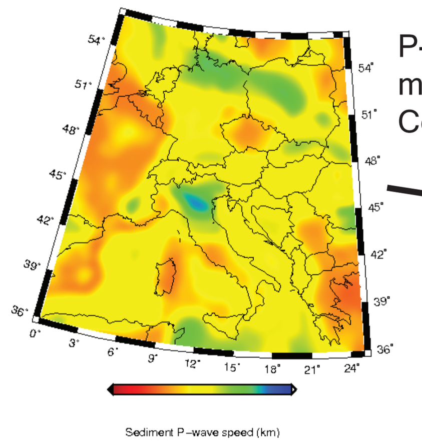
We implement EPcrust-2009 into the ADER-DG method (Dumbser, M. & M. Käser, 2006) and into the spectral element method (Komatitsch & Tromp, 2002) to study the effects of the numerical representation of crustal structures on seismic wave propagation.

KNOWLEDGE OF EUROPEAN CRUSTAL STRUCTURE

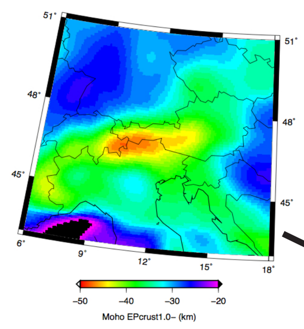
Several models for the European Plate can be found in the literature (Tesauro et all. 2008, Bassin et all. 2000, Grad et all, 2009, Bungum et al., 2004), but none of them has all desired properties respect to resolution, geographical extent, or completeness of specified parameters.

New a priori model of the European plate, EPcrust-2009, is based on a new, comprehensive compilation of currently available information from diverse sources, ranging from seismic prospection to receiver functions studies. Most original information refers to P-wave speed, from which we derive S-wave speed and density from scaling relations (Brocher, 2005). The model covers the whole European plate from North Africa to the North Pole (20°N-90°N) and from the Mid-Atlantic Ridge to the Urals (40°W-70°E). The parameterisation represents the crust in three layers (sediments, upper crust and lower crust), and describes the geometry and the seismologically relevant parameters with a resolution of 0.1° x 0.1° on a geographical latitude-longitude grid (target structural resolution is ~100 km). For each grid point and layer a single set of parameters (seismic velocities Vp, Vs and density) and relative error bars, are specified.

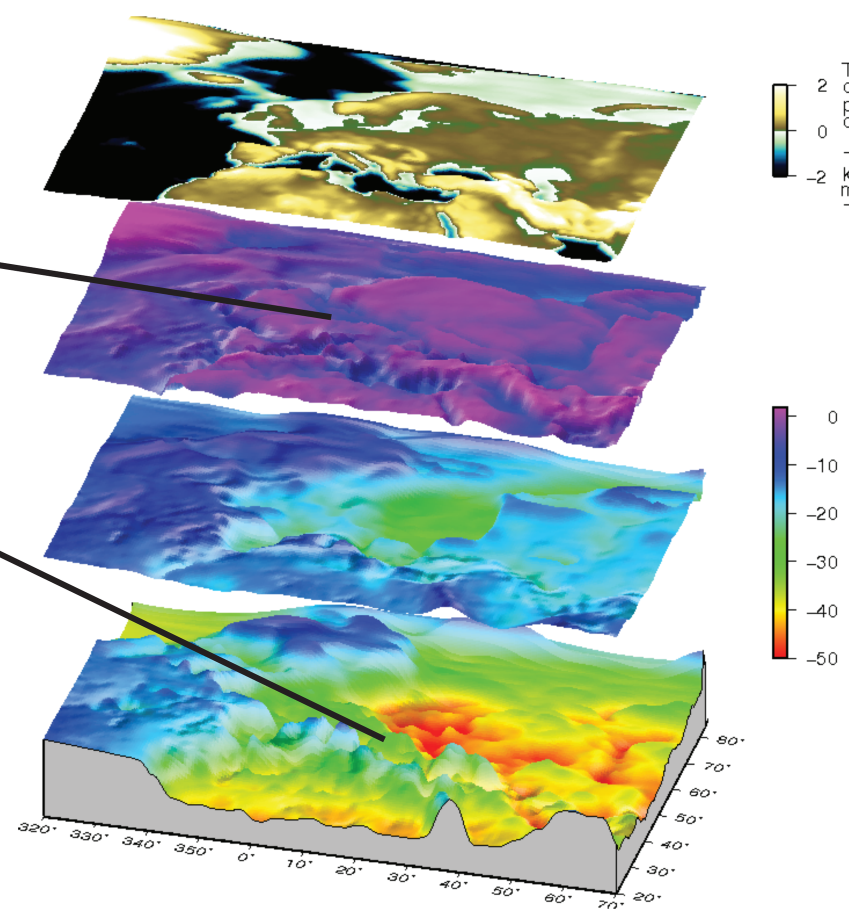
EPcrust-2009



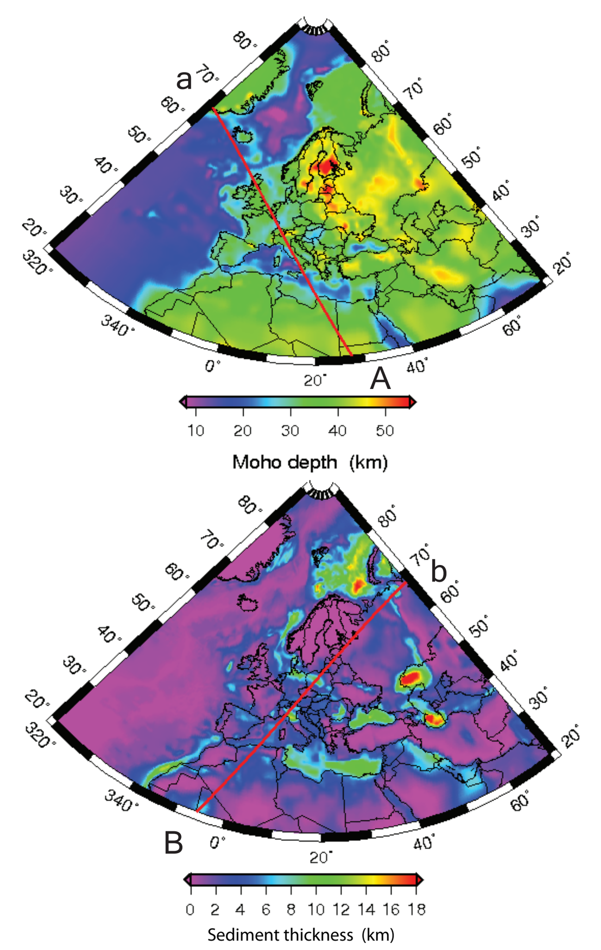
P-wave speed in sediment layer in Italy and Central Europe



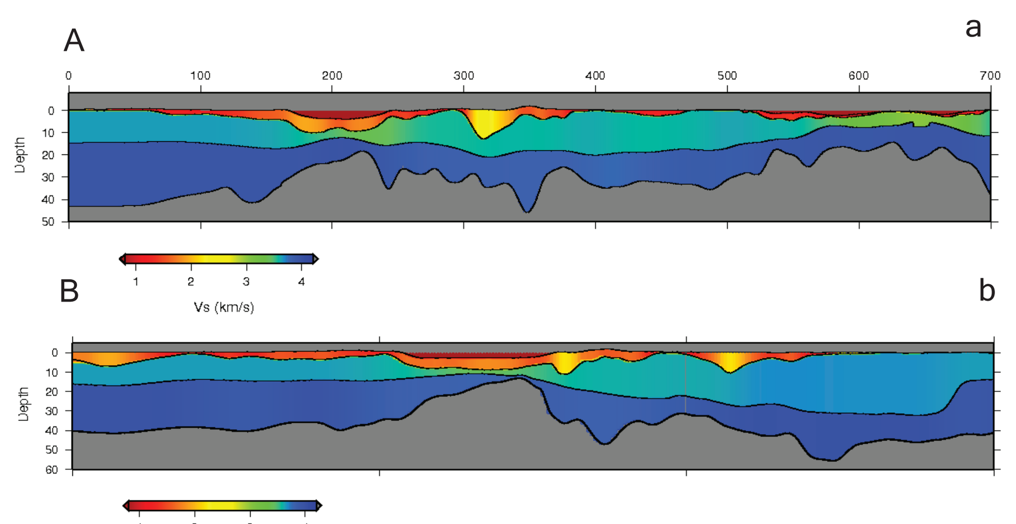
Moho depth of Alps region



Topography, sediment, upper-lower crust and Moho interface depth in EPcrust2009



Moho depth (top) and sediment thickness (bottom) in EPcrust2009

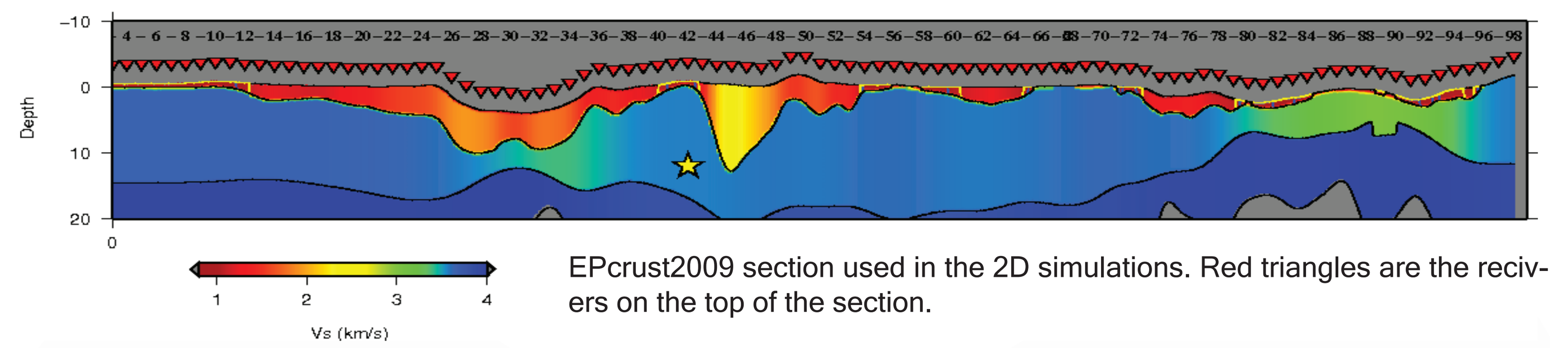


S-wave speed in two sections of the EPcrust2009.

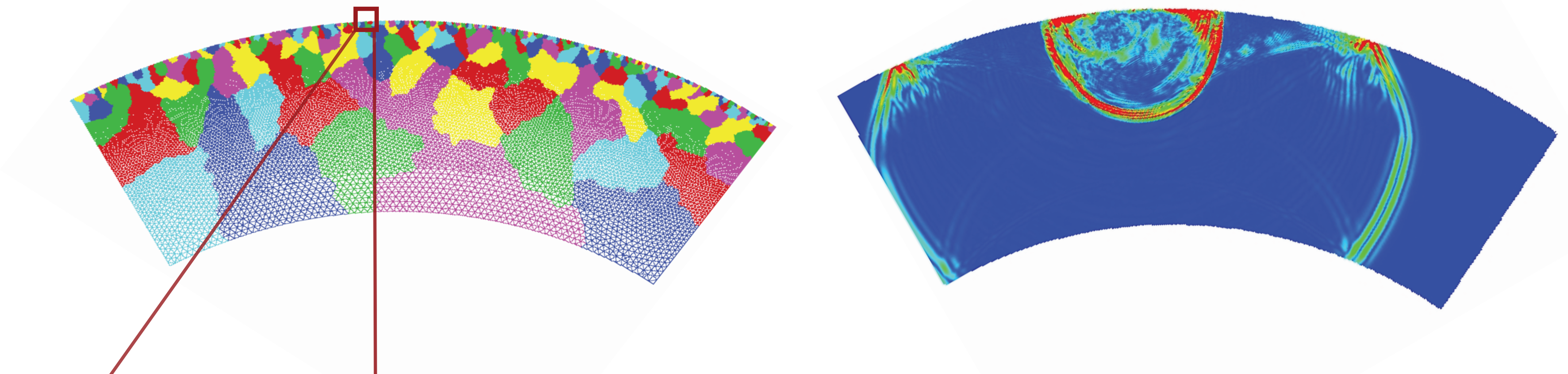
REPRESENTATION OF CRUSTAL STRUCTURE IN 2D ADER-DG METHOD

Crustal models have very thin layers, for example the sediment layer, that are difficult to honor in numerical meshes. We investigate the effects of different representations of these thin layers on synthetic seismograms using triangular meshes for 2D simulations on a vertical section of EPcrust2009.

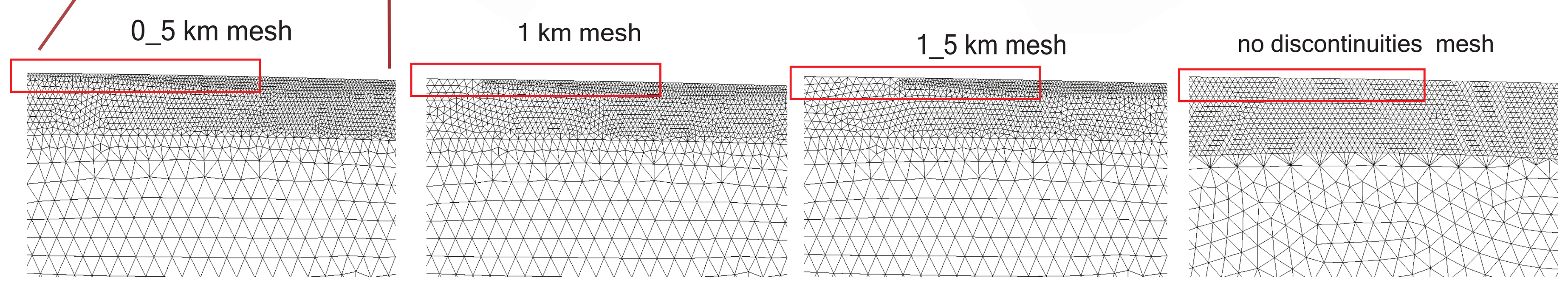
To model seimic wave propagation, we use the Discontinuous Galerkin Finite Element Method (ADER-DG) that achieves high-order accuracy in space and time. With this approach strong and undulating discontinuities can be considered more easily by the mesh and modifications of the geometrical properties can be carried out rapidly due to an external mesh generation process.



EPcrust2009 section used in the 2D simulations. Red triangles are the recivers on the top of the section.



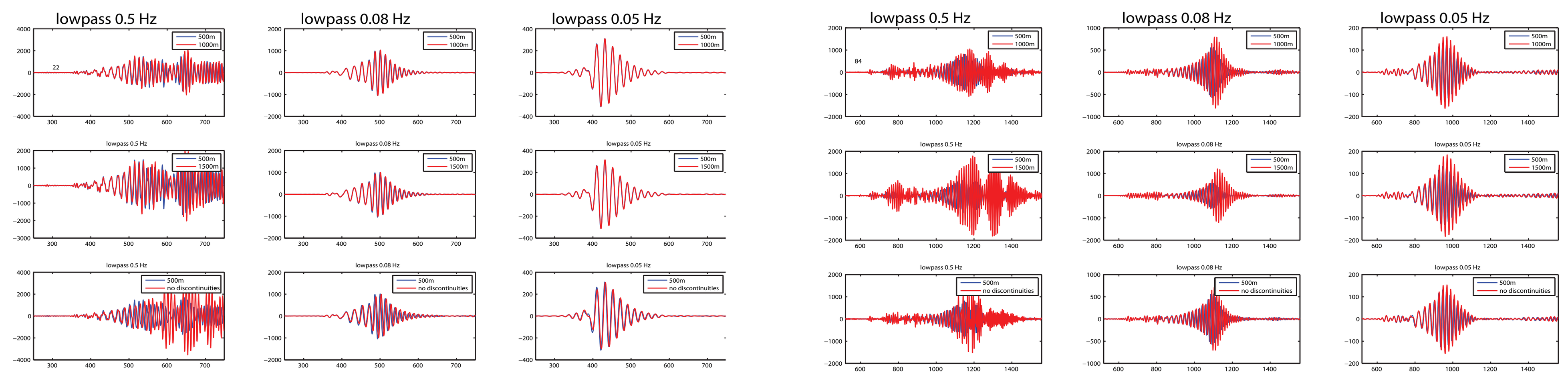
(left) Mesh of the model with MPI partition zones, (right) a snapshot of the wavefield at 200 s. The model has a depth of 2000 km and a length of ~ 6000 km.



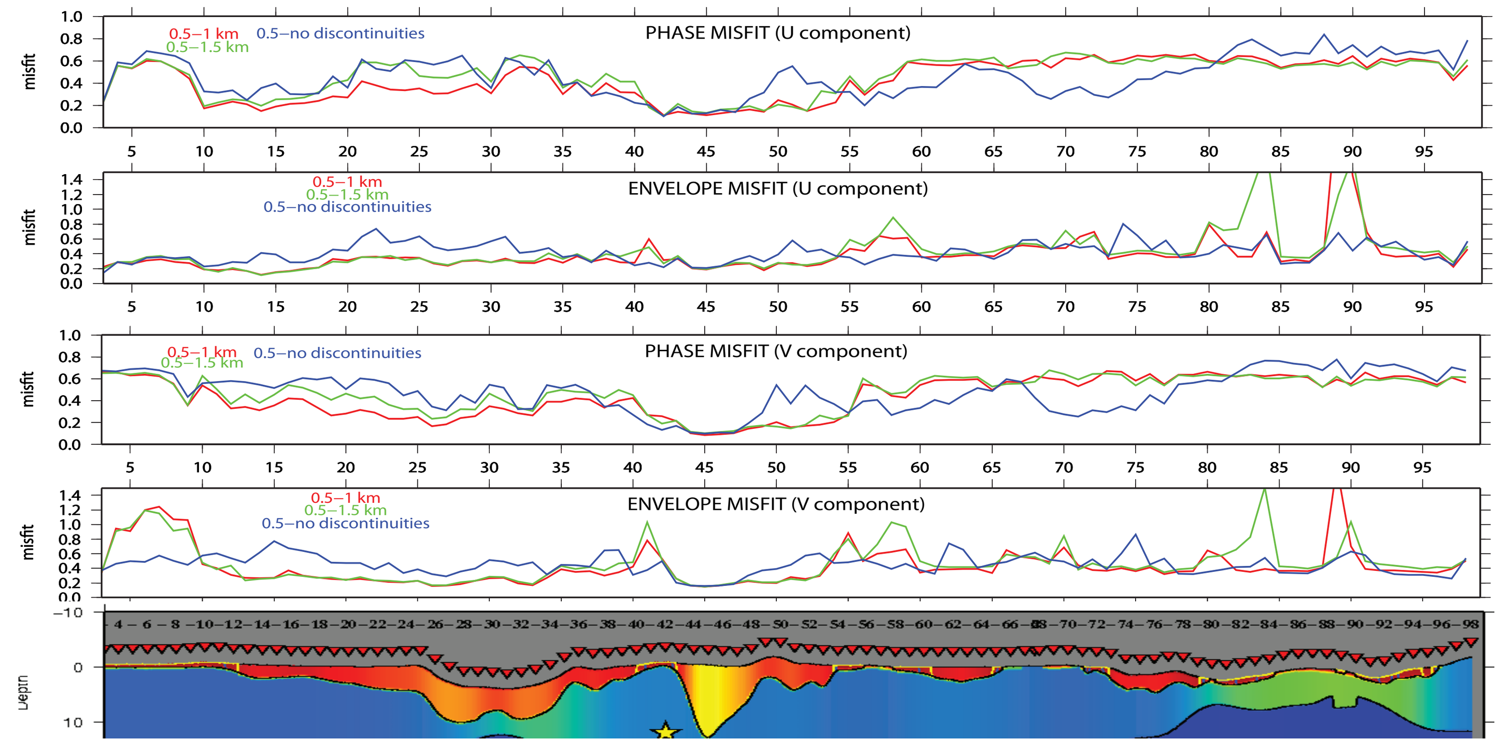
Zooms of the four different meshes considered in this study.

Comparison of seismograms

In order to understand the influence of different mesh representations on recorded data, we calculate the phase and the envelope misfit (Kristekova et al., 2009) between two set of seismograms, keeping the data from 0_5km mesh as the reference dataset.



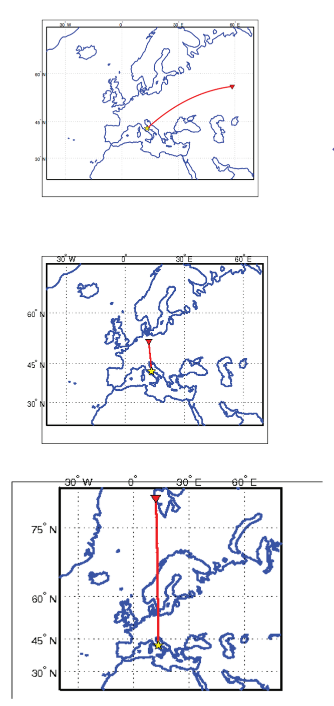
Comparison bewteen seismograms obtained from the 0.5km mesh (reference, blu line) and the other 3 different meshes (red lines). We apply a low-pass filter to the segnals with corner frequency of 0.5, 0.08, 0.05 Hz. The seismograms are 2000 s long.

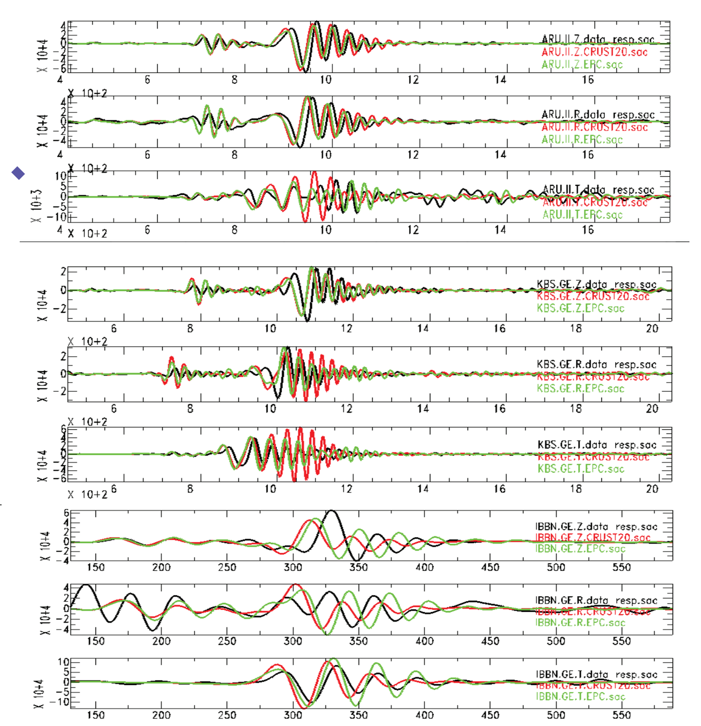


Envelope and phase misfit respect to the reference segnal (seismogram from 0.5 km mesh) calculated in a frequency range of 0.04 - 0.3 Hz (Kristezova et al., 2009).

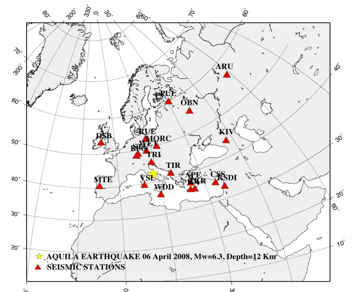
EPcrust-2009 3D SEISMIC RESPONSE IN SEM-METHOD

In order to test our model we compare 3D synthetic seismograms calculated for CRUST2.0+S20RTS (Bassin et al., 2000; Ritsema et al., 1999) and EPcrust2009+S20RTS with real data. We perform the 3D simulations with SPECFEM3D-Globe (Komatitch & Tromp, 2002).

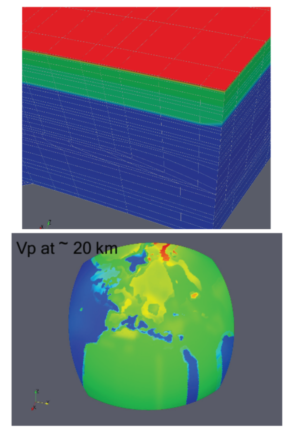




(right) Vertical, radial and transversal component of the displacement for three stations bandpassed between corner frequency of 0.005 and 0.04 Hz (25--200 s). (left) plot of the raypath.



Maps of meshed region



(top) A part of the mesh (bottom) Vp map at 20 km depth as implemented in the mesh

CONCLUSION

Knowledge and representation of the crustal structure is a crucial point in accurate simulation of seismic wave propagation at continental distance.

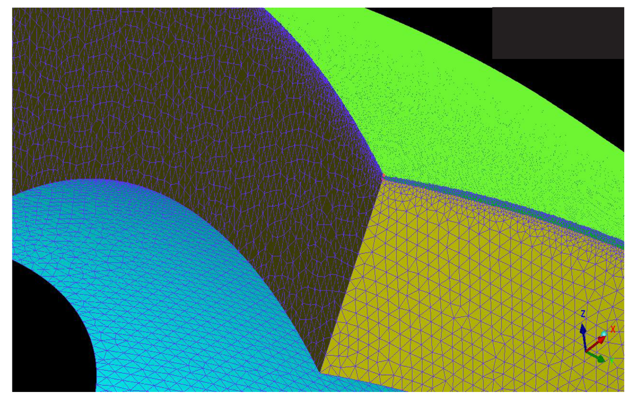
We put the new a priori crustal model for the whole European plate, EPcrust2009, to the test comparing numerical seismograms to recorded data.

We focus our attention on the representation of very thin and shallow layers in the meshes in order to create the best 3D representation of our European model, that achieve a good compromise between computational time and accuracy in the representation of the model.

In our 2D test we evaluated the performance of different representations in numerical meshes of the sedimentary layer: for the frequency range between 0.04 and 0.3 Hz we can conclude that, if the velocity contrast between the two layers is not so strong and the layer is thin, we can neglect this layer in the mesh without losing in accuracy.

FUTURE WORK

We plan to refine our 2D test and precisely implement our model in 3D tetrahedral meshes in order to perform accurate simulation with the ADER-DG method. Numerical simulations will assess weaknesses of the model, therefore contributing to its improvement.



REFERENCES

- Bassin, C. Laske, G. & Master G., 2000. The current limits of resolution for surface wave tomography in North America, EOS, 81.
- Molinari I. and A.Morelli, Representation of crustal structures and surface-wave modeling, Geophysical Research Abstracts, EGU General Assembly 2009, Vol. 11, EGU2009-0, 2009.
- Komatitsch, D & Tromp, J., 2002. Spectral-element simulations of global seismic wave propagation-I . Validation, Geophys. J. Int., 149, 390-412.
- Tesauro, M., M.K. Kaban, and S. A. P. L. Cloetingh (2008), EuCRUST-07: A new reference model for the Eu- ropean crust, Geophys. Res. Lett., 35
- Grad, M., Tiira, T., and the ESC Working Group (2009), the Moho depth map of the European Plate, Geo- phys. J. Int. 176, 279-292. http://www.seismo.helsinki.fi/mohomap/
- Dumbser, M., and M. Käser (2006). An Arbitrary High Order Discontinuous Galerkin Method for Elastic Waves on Unstructured Meshes II: The Three-Dimensional Isotropic Case, Geophysical Journal International, 167(1), 319-336
- Kristekova M., J. Kristek amd Peter Mozco (2009), Time-frequency misfit and goodness-of-fit criteria for quantitative comparison of time signal, Geophys. J. Int,. 178, 813-825.
- Brocher T. M (2005), Empirical Relations between Elastic Wavespeeds and Density in the Earth´s Crust, Bullettin of the Seismological Society of America, Vol. 95, No. 6, pp. 2081-2092.

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